

# Antony van Leeuwenhoek<sup>1</sup>: Tercentenary of His Discovery of Bacteria

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## INTRODUCTION

Three hundred years ago Anthony van Leeuwenhoek (Fig. 1) wrote some of the most remarkable and significant communications in all scientific literature. According to Dobell (6), about 200 letters and manuscripts were addressed to the Royal Society of London, and to other notable organizations and people. Several of the more important of these communications deal with the discovery of microorganisms, especially bacteria, in 1676.

Besides the documents in the Royal Society's archives, a few are preserved in the University Library at Leiden, the Municipal Museum at The Hague, the National Library in Florence, and in the Leibniz Collection at Hanover. Since Leeuwenhoek was proficient only in his native language, all his original correspondence was in Dutch. However, many of his letters were delivered after being transcribed into Latin, and some have been translated into English or other languages and so published.

Leeuwenhoek's letters usually told of new discoveries, often in entirely different fields. His wide-ranging investigations and microscopy observations appear as isolated pieces of information in his curious search for truth about Nature, rather than as systematically organized and extensive studies on a few subjects (6, 8).

The extraordinary variety of things investigated by Leeuwenhoek cover an immense field and contain studies on matters botanical, chemical, microbiological, physical, physiological, medical, and zoological. These have been compiled by Miall (9) and Richardson (10), and include observations in part of the following.

<sup>1</sup> According to Dobell (6), Leeuwenhoek signed his name in different ways. Before 1683 he generally used the spelling Antoni Leeuwenhoeck, with the Christian name ending with a long *i* (equivalent to English *y*) and the surname with *ck*, and without *van*; also sometimes Antoj Leeuwenhoek until 1685 when he inserted *van*. Various English versions of his letters show 19 different ways of spelling his surname.

*Animalcules:* Molds on meat; protozoa, bacteria, and yeast in water and various sorts of infusions; microorganisms in scrapings from teeth.

*Blood:* Red blood cells from many animals and man; capillary flow of blood through tail of tadpole, caudal fin of eel, web of frog's foot, membrane of bat's wing.

*Feathers:* Structure of feathers from various birds.

*Gunpowder:* Microscopic nature before and after firing.

*Hair:* Color and structure of hair or fur from bear, beaver, elk, man, sheep.

*Insects:* Structure of the eye, optic nerve, brain, mouth parts, legs, thorax, and abdomen of the bee, beetle, gnat, fly, louse, mite, silk-worm; spider and its web. First noticed the difference in posture of anopheline and culicine mosquitoes in water.

*Minerals:* Structure of metals (gold, silver, copper), rocks, crystals, salt; properties of a magnet.

*Muscle fibers:* Sections of muscles from various fish, duck heart, whale.

*Scales:* Structure of scales from many fish.

*Spermatozoa:* Structure of spermatozoa from many species; he thought sperm was the veritable germ, which was only hatched by the female.

*Spices, nuts, seeds:* What made pepper hot; the structure in relation to smell and taste of coffee, tea, nutmeg, ginger, sage, etc.

*Trees and plants:* Examined leaves and sections of bark and wood from cork, elm, fir, ebony, lime, oak; plant and vegetable structures, establishing differences between mono- and dicotyledonous plants; why nettles sting, etc.

The scope of this paper is limited to the discovery of bacteria, and the above topics studied by Leeuwenhoek will not be discussed in detail. The information is available in the literature cited (1-13, 18).

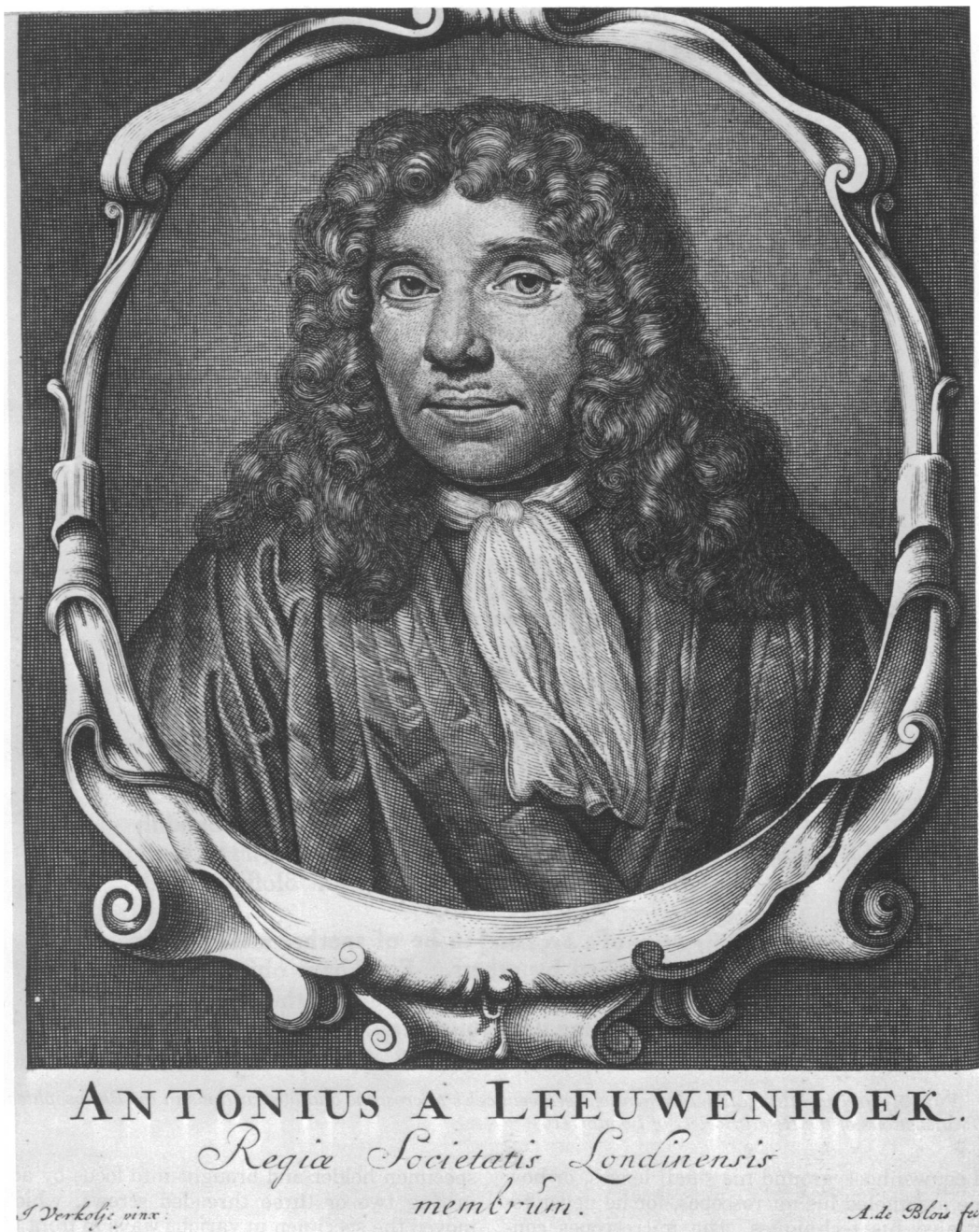


FIG. 1. From *Arcina Naturae Detecta ab Antonio van Leeuwenhoek* (1695). Delphis Batavorum, apud Henricum a Krooneveld (17). (Courtesy John Martin Collection, Health Sciences Library, University of Iowa.)

### LEEUVENHOEK'S MICROSCOPES

The scientific world first learned of Leeuwenhoek's microscope in 1673 when R. de Graaf sent a communication (Fig. 2) to Henry Oldenburg, Secretary of the Royal Society of London

(14). This first communication describes the microscopy observation of molds, and the sting of a bee. For the next 40 years, Leeuwenhoek studied with endless patience and extraordinary acuteness the many items listed above.

Little information is available about how

*A Specimen of some Observations made by a Microscope, contrived by M. Leewenhoeck in Holland, lately communicated by Dr. Regnerus de Graaf.*

**T**HE person communicating these Observations, by and by to be delivered, mentions in a Letter of his, written from *Delph* April. 28. 1673. that one Mr. *Leewenhoeck* hath lately contrived Microscopes excelling those that have been hitherto made by *Eustachio Divini* and others; adding, that he hath given a *specimen* of their excellency by divers Observations, and is ready to receive difficult tasks for more, if the Curious here shall please to send him such: Which they are not like to be wanting in.

*The Observations themselves.*

1. The *Mould* upon skin, flesh, or other things, hath been by some represented to be shoot out in the form of the stalks of Vegetables, so as that some of those stalks appeared with round knobs at the end, some with blossom-like leaves. But I do observe such Mould to shoot up first with a straight transparent stalk, in which stalk is driven up a globous substance, which for the most part places it self at the top of the stalk, and is follow'd by another globul, driving out the first either side-ways, or at the top, and that is succeeded by a third and more such globuls; all which make up at last one great knob on the stalk, an hundred times thicker than the stalk it self. And this knob indeed consists of nothing else than of many small roundish knobs, which being multiplied, the big knob begins to burst asunder, and then represents a kind of Blossoms with Leaves.

2. The *Sting* of a *Bee* I find to be of another make than it hath been described by others. For I have observed in it two other stings, that are lodged within the thickness of the first sting, each having its peculiar sheath.

3. Further

FIG. 2. First scientific announcement of Leeuwenhoek's microscope and observations in the *Philosophical Transactions of the Royal Society of London* (14).

Leeuwenhoek ground his small lenses, or how he assembled his microscopes, for he never revealed his techniques. The microscopes consisted of a highly polished double-convex lens mounted in pierced and beveled openings between two small (about 2 by 4 cm) brass, silver, or even gold plates, which were riveted together (Fig. 3). Leeuwenhoek's special skill lay in polishing and mounting the lens between the metal plates, in obtaining the proper source of light, and in focusing on the object. Objects to be viewed were mounted on a small pin or

specimen holder and brought into focus by adjusting two or three threaded screws, which moved the specimen in various ways in front of the lens.

Leeuwenhoek either built microscopes magnifying several hundred times and with a resolving power of about 1  $\mu\text{m}$ , or he used a special technique for viewing and lighting objects that he never divulged. According to Roosboom (11), the most powerful of his instruments still in existence (Utrecht University Museum) magnifies 275 $\times$  and has a resolving

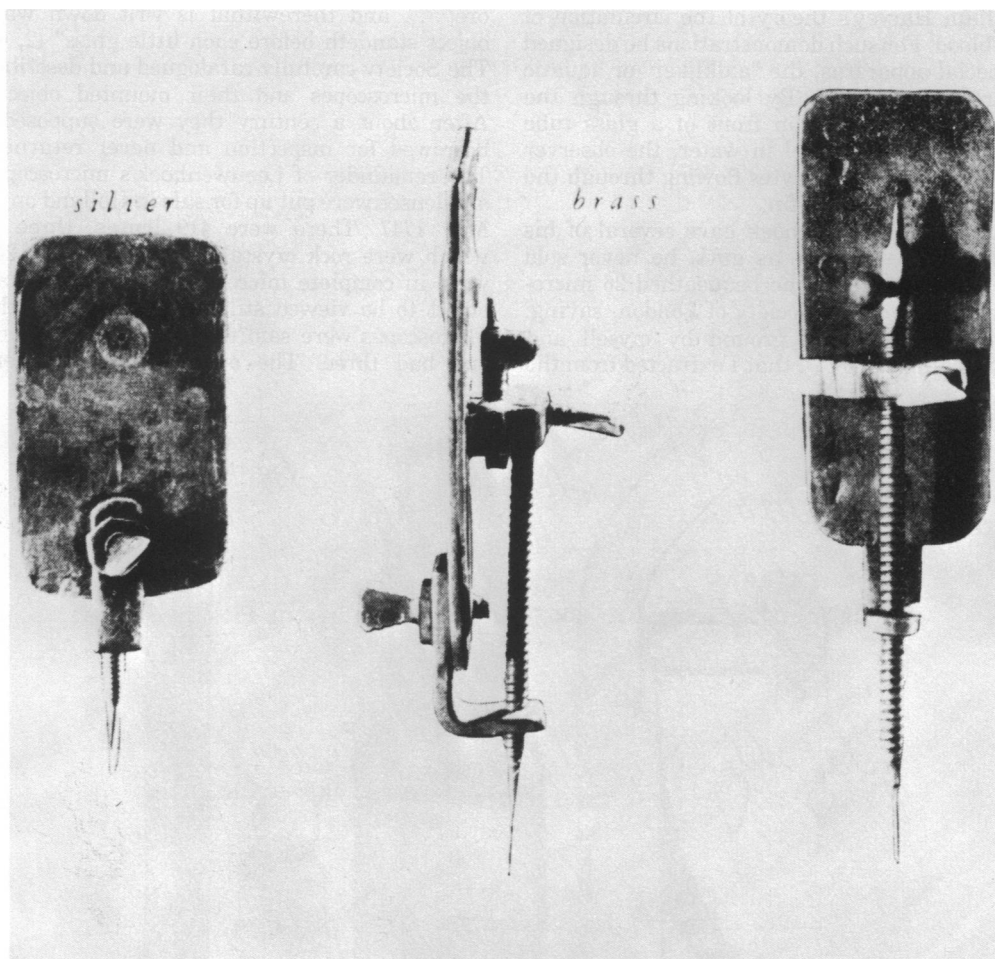


FIG. 3. Three microscopes made and used by Leeuwenhoek between 1673 and 1723. Left, Front or viewing side showing small lens in the metal plate (1.8 by 4.0 cm); center, longitudinal view; right, back view of instrument. From Rooseboom (11) (courtesy of A. J. F. Gogelein, Director, National Museum for the History of Science, Leiden, Netherlands).

power of  $1.4 \mu\text{m}$ , despite scratches on the lens. On the other hand, Cittert (13) states that one of Leeuwenhoek's lenses has resolving power of  $0.7 \mu\text{m}$ , and unstained cells of  $5 \mu\text{m}$ , and stained ones of 1 to  $2 \mu\text{m}$ , are easily observable with it.

Many persons have wondered why Leeuwenhoek preferred a simple microscope for his scientific observations rather than a compound one, which was already known. The compound instrument requires a less powerful lens system, provides a larger field of view, and is easier to use because the object can be placed at a greater distance from the lens. Rooseboom (11) explains that this

is readily understandable if we compare the chromatic aberration of the two types of microscope. With the compound one, the image

formed by the objective, which shows colored fringes, is once more enlarged, together with all its defects, by the eyepiece. With a single, short-focus lens—although, admittedly, the images formed by the different component rays of white light do not fall in one and the same plane, and they too differ in size—the simple microscope is held so close to the eye that one sees the image practically from the center of the lens . . . and the contours hardly show any colored fringes at all.

Once Leeuwenhoek became well known for making microscopes he was visited by many notable people, including Queen Mary of England, Frederick I of Prussia, and Peter the Great of Russia. He frequently demonstrated to visitors the transition of blood from the arterial to the venous system, and thereby confirmed

William Harvey's theory of the circulation of the blood. For such demonstrations he designed a special apparatus, the "aalkijker" or aquatic microscope (Fig. 4). By looking through the microscope mounted in front of a glass tube containing a small eel in water, the observer could see the erythrocytes flowing through the capillaries of the tail fin.

Although Leeuwenhoek gave several of his microscopes to people as gifts, he never sold one. Upon his death he bequeathed 26 microscopes to the Royal Society of London, saying: "Every one of them ground by myself and mounted in silver . . . that I extracted from the

ore . . . and therewithal is writ down what object standeth before each little glass" (2, 6). The Society carefully catalogued and described the microscopes and their mounted objects. After about a century they were supposedly borrowed for inspection and never returned. The remainder of Leeuwenhoek's microscopes and lenses were put up for sale in Holland on 29 May 1747. There were 419 lenses, three of which were rock crystal. Of these lenses, 247 were in complete microscopes, many with an object to be viewed still in place. Two of the microscopes were said to have two lenses and one had three. The other 172 lenses were

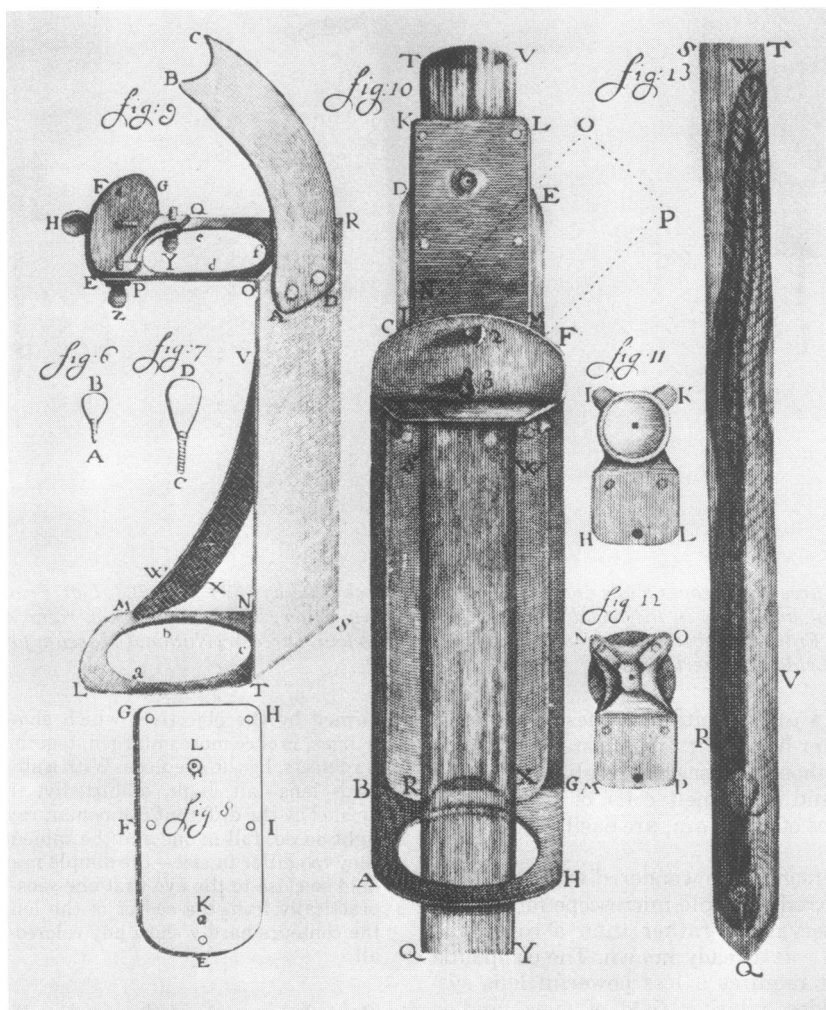


FIG. 4. Drawing of Leeuwenhoek's aquatic microscope. Left, Resilient metal apparatus (fig. 9) for mounting microscope (fig. 8) at top left-hand side. Right, Glass tube containing a small eel (fig. 13). Center, Aquatic microscope (fig. 10) ready for use with glass tube held in place by resilient metal behind the microscope. Special fittings (fig. 11 and 12) for admitting and focusing incident light to the top of microscope. From Rooseboom (11) (courtesy of A. J. F. Gogelein, Director, National Museum for the History of Science, Leiden, Netherlands).

mounted between plates; of these, 160 plates were of silver, 3 were of gold, and 9 were of brass (20). Supposedly, some of those made of gold and silver were sold according to weight. Probably no other microscopes have ever been sold on such a basis (7).

Specifications for making a replica of Leeuwenhoek's microscope have been clearly described by Walter and Via (19).

## DISCOVERY OF BACTERIA AND OTHER MICROORGANISMS

From the many letters of Leeuwenhoek that followed his first one in 1673 concerning molds (Fig. 2), it is a bit difficult to say exactly when he first saw bacteria and other microorganisms. But in 1674 he began to write about his studies on protozoa, and the following year he observed several kinds in canal water and in infusions of pepper and other spices. By this time he had perfected his microscopes and techniques, but he never revealed the methods used for making his best observations, since he kept these for himself.

On 9 October 1676 Leeuwenhoek sent a seventeen and a half page letter to Oldenburg in London outlining his ingenious observations on "animalcules" in various kinds of water and infusions; the observations covered a period of about a year previous to his writing the letter. This unique document is on file in the archives of the Royal Society (15), and it has been carefully translated by Dobell (6), Cohen (4), and others. The best translation and reproduction is that of Cohen in his excellent monograph: *The Leeuwenhoek Letter*. Cohen states, however, that the handwriting is that of a copyist and not Leeuwenhoek's, although he did make some corrections in the manuscript and he signed it. Since the letter is not the handwriting of Leeuwenhoek, none of the pages will be reproduced here, although translated quotations will be given to show his discoveries. His handwriting is shown in Fig. 6.

Certain sections of the 9 October letter that undoubtedly refer to Leeuwenhoek's discovery of bacteria and other microorganisms in water and infusions of pepper are as follows (4, 6, 12):

[*The 1st Observation on Pepper-Water*]: On 24 April 1676 . . . the fourth sort of animalcules which floated about amongst the other three sorts, were incredibly small, indeed so small . . . that I judged if all of 100 of these . . . were stretched out against one another, they would not reach the length of a small sand-grain. This being true, then ten hundred thousand of these living creatures would not be able to fill the volume of a small sand-grain.

[*The 3rd Observation on Pepper-Water*]: The

4th of June. . . I saw a great multitude of living creatures in one drop of water, amounting to no less than 8 or 10 thousand, and they appear to my eye through the microscope as common sand does to the naked eye.

[*The 5th Observation on Pepper-Water*]: The 6th of August. . . This was to me, among all the marvels that I have discovered in Nature, the most marvellous of all; and I must say for my part, that no greater pleasure has yet come to my eye than these spectacles of so many thousands of living creatures in a small drop of water moving among one another, each individual creature with its particular movement. And if I said there were a hundred thousand in one droplet. . . I should not err. Others viewing this would multiply the number by fully ten times, but I state the least. My method for seeing the very smallest animalcules I do not impart to others; nor how to see very many animalcules at one time. This I keep for myself alone.

All authorities agree that the above observations by Leeuwenhoek constitute the original discovery of bacteria.

In Leeuwenhoek's letter no. 32 of 14 June 1680 to Thomas Gale, at that time Secretary of the Royal Society, he recorded (3, 17) the first microscopy study of yeast in fermenting beer wort and noted that they gave off much gas. He said, "some of these seem to be quite round, others are irregular, and some exceeded the others in size consisting of two, three, or four of the aforesaid globules joined together." In the same interesting letter he states that he has heard that no living creature can generate itself when placed in tightly stoppered vessels. Thus he decided to study the topic by preparing a clean-water infusion of pepper in two glass tubes, one remaining open to the air and the other sealed (G, in Fig. 5). After the third day he examined the water from the open tube and saw many animalcules under the microscope, but he decided to wait until the fifth day to break the seal and examine the contents of the closed tube. When he did this he was amazed to find many bacteria. This was the first demonstration that organisms live and multiply under facultative or anaerobic conditions, but Leeuwenhoek was unable to appreciate the full significance of his study.

If any one should doubt that Leeuwenhoek first saw and described bacteria and certain other microorganisms in 1676 and again in 1680, proof of this certainly came in 1683. A letter (16) addressed to the Royal Society on 17 September 1683 is probably as famous in the annals of microbiology as the one of 1676 or any letter ever written. The letter contained an account of the types of animalcules seen in the saliva (spittle) and tooth scrapings from his



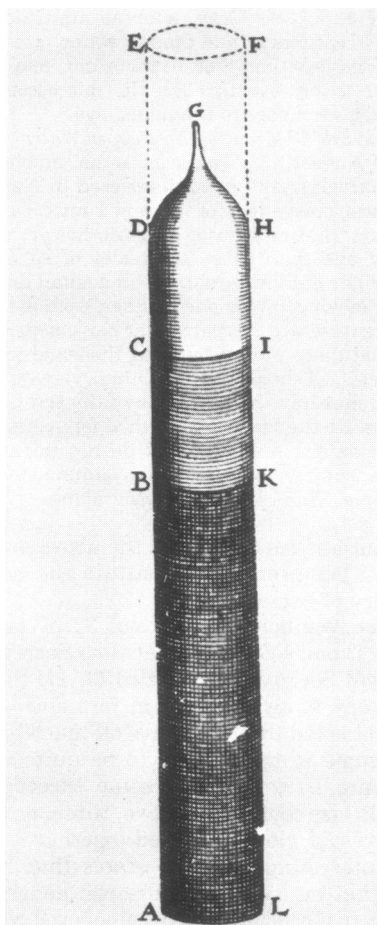


FIG. 5. Leeuwenhoek's sealed tube for determining if animalcules would grow in the absence of open air. Pepper (ABKL)-rain water (BCIK) infusion with tube sealed at G (2, 6, 17).

mouth and those from others, as well as speculation on how the organisms got into the mouth.

Figure 6 is a page from Leeuwenhoek's 1683 letter, which demonstrates his handwriting and clearly describes his drawings of microorganisms (Fig. 7). The translation (6, 16) of part of the previous and following pages, as well as the one shown in the figure, follows:

The biggest sort had the shape of A [Fig. 7]; these had a very strong and nimble motion, and they shot through the water or spittle, as a Pike does through the water. These were almost always few in number.

The second sort had the shape of B. These often spun about like a top, and sometimes took a course as shown between C and D. They were more numerous than the first.

In the third sort I could not well distinguish

the fig: sometimes, it seemed to be oval and at other times it was round. These were so small that I could see them no bigger than fig. E; yet they went ahead so nimbly, and they hovered so together, that I can compare them to nothing better than a big swarm of gnats or flies, flying in and out among one another. These last seemed to me to be . . . several thousand in an amount of water, or spittle (mixed with the aforesaid material) no bigger than a sand grain. . . .

Besides these . . . there were a great quantity of streaks or threads of different length but of the same thickness, some bent, others straight, as fig. F, and which lay disorderly ravelled together. Because I had seen formerly in water live animals that had the same fig., I made every effort to see if there was any life in them; but I could make out not the least motion, that looked like anything alive in any of 'em. . . .

The biggest sort (whereof there were a great many) bent themselves in curves as they moved like fig. G.

### LEEUEWENHOEK THE MAN

The biography of Leeuwenhoek can be related quickly, because there is so little information about his personal activities during a greater part of his life. He was born in Delft, Netherlands, 24 October 1632, and he died there in his 90th year (26 August 1723) and was buried in the Old North Church. He was from good Dutch stock, although not of great distinction; his genealogy is outlined in detail by Schierbeek (12). As a boy he had some schooling and lived for awhile with an uncle who was an attorney and town clerk at Benthuisen—a short distance from Delft. There is no indication, however, that he planned to be a lawyer.

When Leeuwenhoek was 16 he went to Amsterdam to apprentice as a linen draper. After qualifying, he also became the bookkeeper and cashier in the shop where he worked. In about six years (1652–54) he returned to Delft, married (18) and sired five children (all but one daughter, Maria, died in childhood). He bought a house and shop, and set up in business as a draper. At the age of 27 or 28 he was appointed Chamberlain of the Council Chamber of the Sheriffs of Delft. This position paid only a small salary, but it did not require arduous or time-consuming duties so he could devote more attention to his study of Nature. He did, however, do some work as a surveyor and as minicipal wine-gauger. When and why Leeuwenhoek began to grind and mount lenses is not known.

Leeuwenhoek was one of the most original and curious men who ever lived. It is difficult to compare him with anybody because "he belonged to a genus of which he was the type and

We hadden een seer sterke en vaardige beweginge, en  
 schooten door het water, of speeksel, als een Insek door  
 het water doet. Dese waren meest door gaant loeying int  
 getal. De tweede soort hadde de fig. van B. dese draijde  
 haar veeltyts om als een Tol, en namen, soo vint als dan  
 een koms als met C. en D. is aen gewesien. Dese waren  
 veel meerder int getal. Aan de derde soort en londe  
 ik geen fig. bekennen, want op de eene tijt schenen  
 deselve te bestaan nijt een Lang. ront, en op de ander  
 tijt weder nijt een ront, Dese waren soo klein, dat  
 ik deselve niet grooter londe sien als fig. E. en daar  
 bij, soo een vaardige beweginge voortgang, dat deselwige  
 soo door malckanderen, stierden, als of wy ons in  
 beelden, een groot getal van Niggen of Vliegen  
 door malckanderen te sien vliegen. Dese laatste sijn  
 mij wel te vooren gekomen, dat ik oordeelde eenige  
 dijnenden, te sien inde quantiteit water, of speeksel  
 (vermengt met de verhaalde materie) dat niet grooter  
 was als een Sant groote, schoon <sup>datter</sup> wel g. deelen water,  
 en 1. deel materie was, dat ik tusschen mijn tanden  
 of tussen had nijt genomen. Voorders bestont de  
 meeste materie nijt een over groote menigte van Strom-  
 tgen, de eene veel van den anderen vertakende inde  
 Lichte, en mochtant van een ende deselve dikte, de eene  
 krom gebogen, ende de andere regt, als fig. F. Die onge-  
 schikt door malckanderen Lagen, en om dat ik voor  
 desen, drinkend int water heb sien Leven, die deselve  
 fig. hadden, soo heb ik alle desonem aen gewent, om  
 te sien, of daar Leven in was, Maar ik heb geen  
 de minste beweginge, dat na eenig Leven gelek, daar  
 aen

FIG. 6. Page from the original manuscript of Leeuwenhoek's letter 39 to the Royal Society of London dated 17 September 1683 in which he described the bacteria in Fig. 3. This is a good example of his handwriting at the age of 51. See text for translation. (Courtesy of Dobell [6].)

only species" (5), and when he died his line became extinct.

Even in the 17th century most great naturalists were learned men, who studied under emi-

nent professors, knew Latin or Greek together with their native language, and acquired and rearranged traditional knowledge to suit their own needs. Leeuwenhoek had some formal edu-



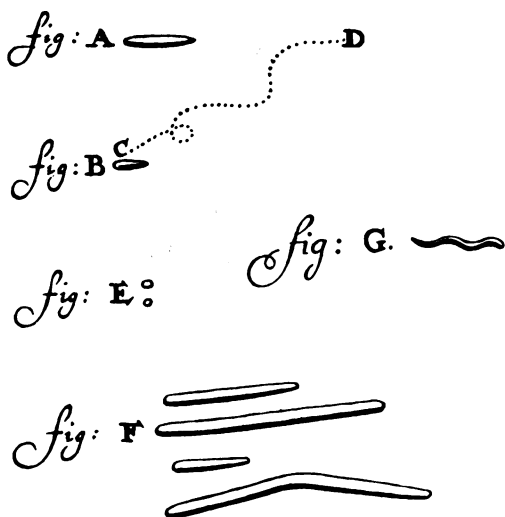


FIG. 7. Leeuwenhoek's drawings of bacteria (bacilli, cocci, spirillum) from the human mouth as described in letter no. 39, 17 September 1683. See Fig. 5 and text for descriptions (7, 13).

cation, but he studied under no distinguished professor, owed nothing to any university, and knew no language but his own. He was largely self-educated and had to rely entirely on his own innate genius and curiosity in studying the secrets of Nature. He could only ask Nature questions in 17th century Dutch, and then puzzle about her answers by himself. Because of his originality, discoveries, and extensive contributions, Leeuwenhoek was elected a foreign member of the Royal Society of London in 1680.

No one can consider Leeuwenhoek as one of the great philosophers of his day. He did, however, have a definite opinion on two great biological questions of the time: spontaneous generation and the origin of species. His own observations supported the reasoning of Redi, that when things arose independently in infusions or tissues they were actually introduced from without. He believed in fixed species, and he expressed views similar to those for which Linnaeus became famous in the next generation. Although Leeuwenhoek studied most things superficially by standards of today, he made many great and original discoveries, and he literally founded protozoology and bacteriology from nothing.

"A few people are born great, some have greatness thrust upon them during their lives, and other achieve greatness by themselves and are fully recognized later" (1). Leeuwenhoek qualifies best under this last category, but he also belongs to another important class. He was one of the unique persons in history who truly

penetrated and discovered some of the great secrets of Nature.

Not only microbiologists, but everyone who has lived since Leeuwenhoek, owe much to this gifted man. On the occasion of the tercentenary of his discovery of bacteria we should gratefully acknowledge and pay tribute to him, as was done graciously on his 300th birthday (7).

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